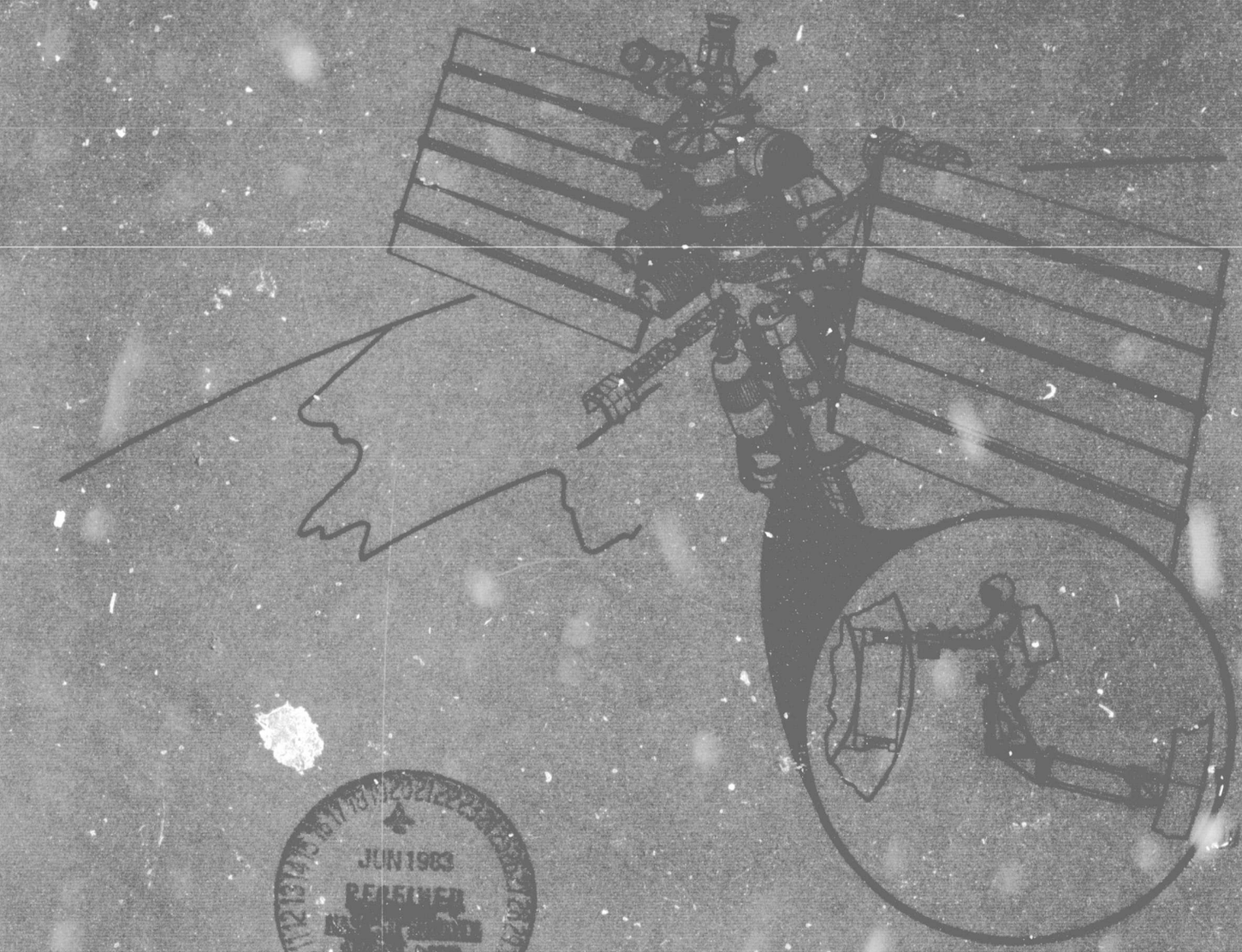
SSS-SR-04-01
NAS8-35042

Volume I

Executive Summary

May 1983

Definition of Technology Development Missions for Early Space Station Satellite Servicing



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SSS-SR-04-01
NAS8-35042

Volume I

Final
Report

May 1983

DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATION SATELLITE SERVICING

Approved by:

Sherman Schrock,
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May 1983

DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATION

SATELLITE SERVICING

EXECUTIVE SUMMARY
FINAL REPORT

Prepared For:

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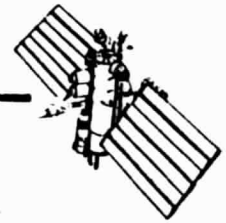
This document is submitted in accordance with the requirements of Contract NAS8-35042, Schedule Article XV, DR-4, and Contractor Task 6.0 of Exhibit A Statement of Work. This document is the Executive Summary for the Final Report.



Executive Summary

Final Report

Definition Of Technology Development Missions For Early Space Station Satellite Servicing

May,1983

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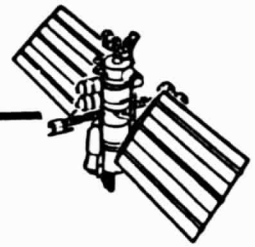
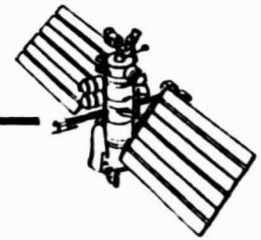
Scope



VOLUME I, EXECUTIVE SUMMARY, SUMMARIZES THE RESULTS AND ACTIVITIES OF THE STUDY. DETAILED STUDY RESULTS ARE PRESENTED IN VOLUME II, TECHNICAL VOLUME, FINAL REPORT.

Satellite Servicing Study Objectives



- DEFINE THE TESTBED ROLE OF AN EARLY (1990) MANNED SPACE STATION IN THE CONTEXT OF A SATELLITE SERVICING EVOLUTIONARY DEVELOPMENT AND FLIGHT DEMONSTRATION TECHNOLOGY PLAN WHICH RESULTS IN A SATELLITE SERVICING OPERATIONAL CAPABILITY BY THE LATE 1990S.

- CONCEPTUALLY DEFINE A SATELLITE SERVICING TECHNOLOGY DEVELOPMENT MISSION (A SET OF MISSIONS) TO BE PERFORMED ON AN EARLY MANNED SPACE STATION.

Satellite Servicing Study Flow

A structured approach was used to ensure all study elements defined.

- Satellite Servicing Mission Model Developed
- Task Assessment Identified All Servicing Tasks/Locations
- Mission Objectives, Scenarios, and Requirements Defined
- Technology Development Plan Established
- TDMs Identified, Developed, and Validated for All Servicing Tasks
- TDM Accommodation Needs and Interfaces Defined
- TDM Costs and Schedules Developed

Satellite Servicing Study Flow

INPUT DATA
- NASA
- MMC
- INTERNATIONAL

DEVELOP SERVICING MODEL
- SATELLITE
- SPACE STATION EVOLUTION
- SATELLITE ASSEMBLY

SPACE STATION STUDY

1984 — 2000

TIME PHASE
SERVICING REQUIREMENTS

SERVICING TASK ASSESSMENT

- MAINT. & RESUPPLY
- ORBIT TRANSFER
- ASSY & CHECKOUT

DEFINE TDM MISSION OBJECTIVES
- SATELLITE
- SPACE STATION
- ASSEMBLY

DEVELOP TECHNOLOGY DEVELOPMENT MISSIONS (TDM)
- MATRIX
- RANKING
- PHASING
- TRADES

ACCOMMODATION NEEDS
- INTERFACES
- SERVICING EQUIP

OPERATIONAL ANALYSIS
- MAN SUPP.
- AUTOMATION
- TIMELINES

PROGRAMMATIC ANALYSES
- OPER. PLAN
- SCHEDULES
- COST ANALYSIS

DEFINE TDM REQUIREMENTS
- MISSION/SYSTEM REQMTS
- INTERFACE REQMTS
- SERVICING EVOLUTION

IDENTIFY NEW TECH. CAPABILITY

GROUND TESTS	SHUTTLE SORTIE	EARLY S.S.

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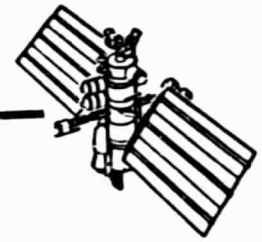

Servicing Tasks, Objectives

And Requirements

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Servicing Mission Model and Task Development

Mission model assessment determined that servicing opportunities are abundant.

- Space Station Mission Model Totals 185 Missions in 1990s
- Each Mission Analyzed for Servicing Tasks
- Seventy Percent of Missions Surveyed Required Servicing
- Three Hundred and Eighty-Seven Servicing Opportunities Were Identified

Servicing Mission Model & Task Development

COMPOSITE MISSION MODEL (389)

TRADE STUDIES

SPACE STATION MISSION MODEL	
S/S PLATFORMS	IFF
CATEGORIES	NO. OF MISSIONS
PLANETARY SCIENCE	11
EARTH OBSERVATION	14
TOTAL	185

SERVICE INTERVALS	
CRYOGENICS	6 MO
STORABLE FLUIDS	30 MO
INSTRUMENT UPGRADE	36 MO
MATERIALS RESUPPLY	1-6 MO
COMPONENT FAILURE	21 MO

SERVICING TASK RQMTS	
TASK	NO.
ASSEMBLY	26
ORBIT TRANSFER	126
RESUPPLY	139
MAINTENANCE	96
TOTAL SERVICE TASKS	387

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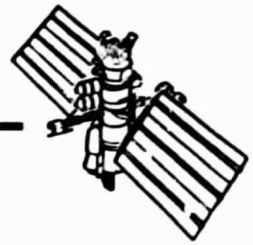
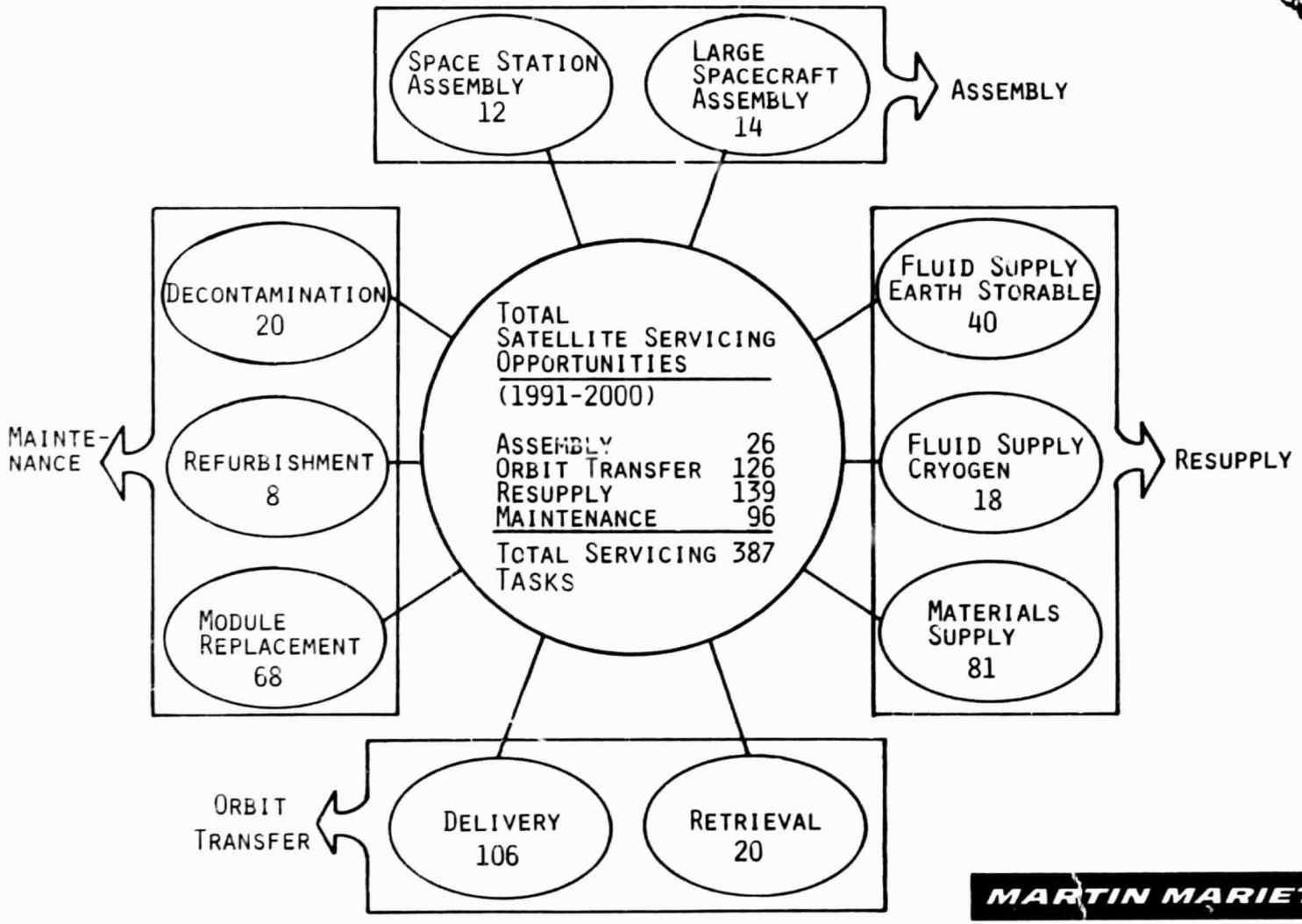
Satellite Servicing Tasks

Survey and analysis defined 387 servicing tasks.

- Four Task Categories Encompass 10 Mission Areas
- Twelve Space Station Assembly and 14 Spacecraft Assembly Missions Identified
- Spacecraft Delivery and Retrieval Missions Are Extensive
- Resupply Provides Satellite Life Extension and Enables Continuous Materials Processing Activities
- Decontamination, and Planned (Module Replacement) and Unplanned Repair Encompass Maintenance Tasks

Satellite Servicing Tasks





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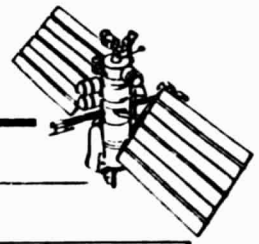
Servicing Task Assessment—Locations

Assessment of task matrix identified full spectrum of servicing tasks and locations.

- All Servicing Tasks and Locations Considered
- Ten Major Tasks Required at Five Locations
- Servicing Required at Space Station and Remote Locations
- Most Tasks Required at All Locations

Servicing Task Assessment–Locations



Servicing Tasks	Servicing Sub-Tasks	Servicing Locations				
		Space Station	S/C Berthed At S/S	S/C In LEO		S/C In GEO
				S/S Plat	User S/C	
Assembly	S/S System Assembly/Modification	✓		✓		
	Large S/C Assembly	✓	✓			
Orbit Transfer	Delivery		✓	✓	✓	✓
	Retrieval		✓	✓	✓	✓
Resupply	Fluids -Earth Storable -Mono, Bi-Prop	✓	✓	✓	✓	✓
	Fluids -Cryogen	✓	✓	✓	✓	✓
	Mtrls - Logistics - Raw Materials	✓	✓	✓	✓	✓
Maintenance	Module Replacement	✓	✓	✓	✓	✓
	Refurbishment	✓	✓	✓	✓	✓
	Decontamination	✓	✓	✓	✓	✓

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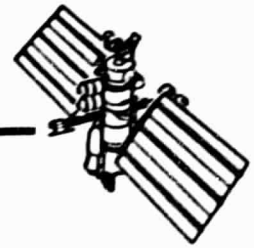
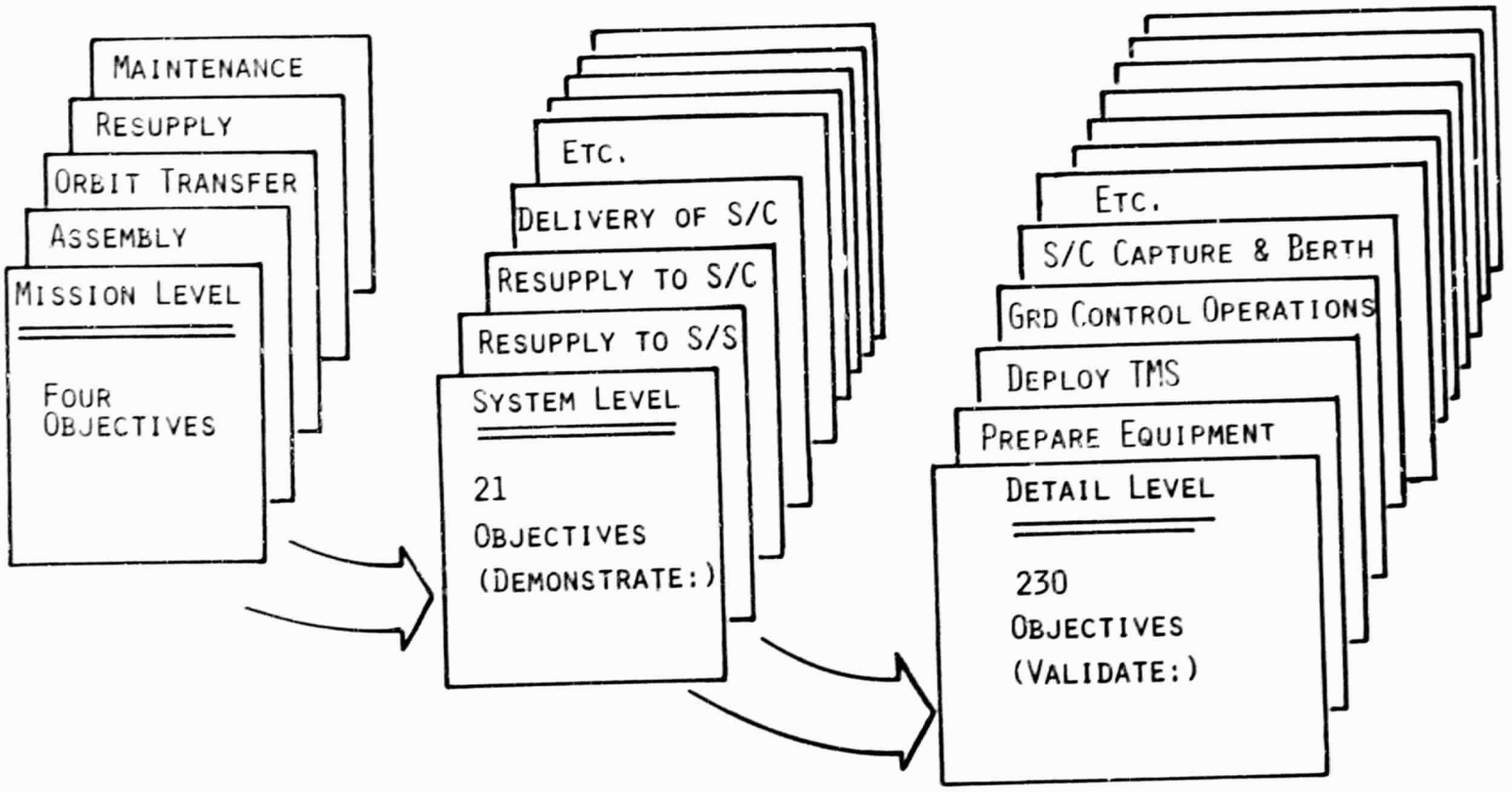
Satellite Servicing Objectives

Mission, system, and detailed objectives defined.

- Resulting in:
  - 4 Mission Level Objectives
  - 21 System Level Objectives
  - 230 Detail Level Objectives

Satellite Servicing Objectives





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Servicing Objectives—Orbit Transfer (Example)

Orbit transfer objectives cover delivery and retrieval tasks.

- Results
  - 5 System Level Objectives Defined
  - 48 Detail Level Objectives Identified

Servicing Objective – Orbit Transfer (Example)

MISSION OBJECTIVE	DEMONSTRATE CAPABILITY TO DELIVER/RETRIEVE SPACECRAFT TO AND FROM OPERAT LEO AND GEO ORBITS AND TO AND FROM THE MANNED SPACE STATION			
SYSTEM LEVEL OBJECTIVE	DEMONSTRATE CAPABILITY TO STACK TRANSFER VEHICLES/SPACECRAFT	DEMONSTRATE CAPABILITY TO LOAD STACK WITH PROPELLANTS	DEMONSTRATE DEPLOYMENT OF STACK TO REMOTE REBOOST POSITION	DEMONSTR TO DELIV TO OPERA
DETAILED OBJECTIVES	VALIDATE MOVEMENT OF TRANSFER VEHICLES (TMS/OTV) TO MATING POSITION ON SPACE STATION USING SPACE STATION RMS VALIDATE MATE OF TRANSFER VEHICLE(S)/ SPACECRAFT USING SPACE STATION RMS, EVA, MMU/SPACE CRANE, CONTROL CONSOLES	VALIDATE CAPABILITY OF SPACE STATION RMS TO TRANSFER STACK TO PROPELLANT STORAGE AREA VALIDATE PROPELLANT LOADING: - POWER STACK DOWN - CONNECT FLUID, ELECTRICAL UMBILICALS - LOAD VEHICLES - VALIDATE LOAD ACCURACY - MONITOR RESIDUALS - DISCONNECT UMBILICALS VALIDATE CHECKOUT OF ORBIT TRANSFER STACK - POWER STACK UP - CONDUCT COMPLETE CHECKOUT OF STACK	VALIDATE SPACE STATION RMS TRANSFER OF STACK TO DEPLOYMENT SITE VALIDATE SPACE STATION RMS DEPLOYMENT OF STACK FROM SPACE STATION VALIDATE TMS TRANSFER OF STACK TO ORBITAL BOOST POSITION VALIDATE SPACE STATION CONTROL CENTER CAPABILITY TO CONTROL VICINITY ENVELOPE	VALIDATE FOR FINAL SYSTEM CH VALIDATE ENGINE I (TMS, OT VALIDATE MISSION MANNED S CONTROL TION GRO PRIOR TO LINE OF VALIDATE SPACECRA OPERATI VALIDATE OF SPAC

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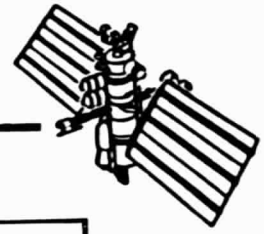
Mission Scenarios

Total set of mission scenarios derived from task assessment and TDM objectives.

- **Task, Locations, and TDM Objectives Primary Inputs**
- **Servicing Techniques Derived—Automation, EVA, and IVA**
- **Result—112 Servicing Scenarios Were Developed for Functional Analysis**

Mission Scenarios



System Level TDM Objectives

Mission Level TDM Objectives

ASSEMBLY
- Demonstrate Capability To Assemble/Modify The Space Station
- Demonstrate On Orbit Assembly Of Large Spacecraft

ORBIT TRANSFER
- Deliver/Retrieve Spacecraft To/From Operational Orbits

RESUPPLY
- Supply Fluids (Earth Storable/Cryogenic) And Solid Objects

MAINTENANCE
- Conduct Preventive, Corrective, And Upgrade Maintenance

Other Variables
- Automated - EVA - IVA

Servicing Task Locations

Servicing Tasks	Servicing Sub-Tasks	Servicing Locations: Space Station	S/C Berthed At S/S	S/C In LEO: S/S Plat	S/C In LEO: User S/C	S/C In GEO
Assembly	S/S Sys. & Assembly/Modification	✓		✓		
	Large S/C Assembly	✓	✓			
Orbit Transfer	Delivery	✓	✓	✓	✓	✓
	Retrieval	✓	✓	✓	✓	✓
Resupply	Fluids - Earth Storable - Mono, Bi-Prop	✓	✓	✓	✓	✓
	Fluids - Cryogen	✓	✓	✓	✓	✓
Maintenance	ORUs - Logistics - Raw Materials	✓	✓	✓	✓	✓
	Module Replacement	✓	✓	✓	✓	✓
	Refurbishment	✓	✓	✓	✓	✓
	Decontamination	✓	✓	✓	✓	✓

Etc

IVA Servicing for SS, Prevent. Maint.

EVA Servicing, Refurbishment, Free Flyer

Orbit Transfer, Payload Deliv. Free Flyer

Remote Svcing for SS, Decontamination

Remote Svcing, Free Flyer, Cryogen Resupply

112 Servicing Scenarios

Time-Phased Sequence
of Servicing Events

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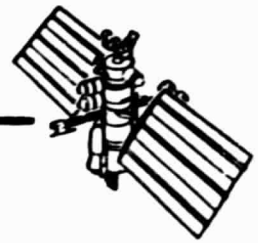
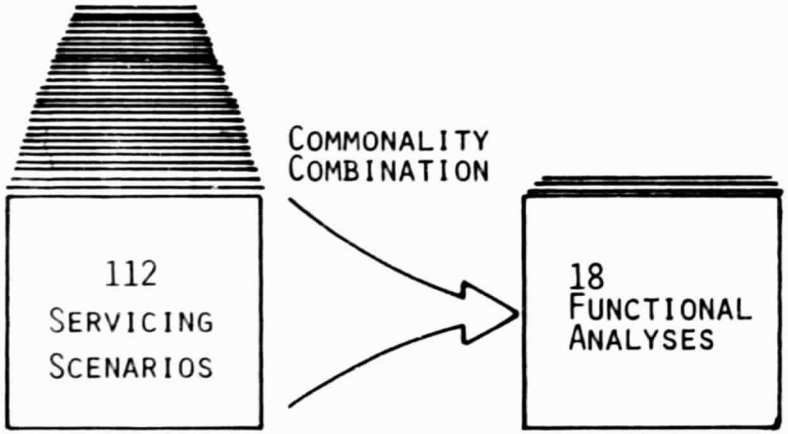
Scenario Commonality and Combination Analysis

Functional analysis completed for 18 unique scenarios.

- One-Hundred and Twelve Scenarios Examined for Commonality and Combinations
- Result—Eighteen Functional Analyses Capture All Servicing Events

Scenario Commonality/Combination Analysis





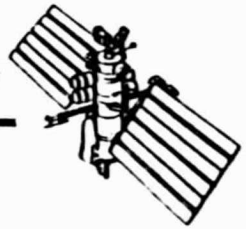
1. AUTOMATED SERVICING, ATTACHED
2. AUTOMATED SERVICING, UNATTACHED
3. AUTOMATED SERVICING FOR SS
4. AUTOMATED SERVICING, PLATFORM
5. EVA SERVICING FOR SS
6. EVA SERVICING FOR FREE FLYER
7. EVA SERVICING, PLATFORM
8. EVA SERVICING, ATTACHED
9. IVA SERVICING FOR SS
10. IVA SERVICING, ATTACHED
11. ORBIT TRANSFER PAYLOAD DELIVERY
12. ORBIT TRANSFER PAYLOAD RETRIEVAL
13. PAYLOAD ASSEMBLY AT SS
14. PAYLOAD MATING AT SS
15. PAYLOAD CONSTRUCTION
16. SS ASSEMBLY, INITIAL
17. SS ASSEMBLY, EVOLUTION
18. SS ASSEMBLY, CONSTRUCTION

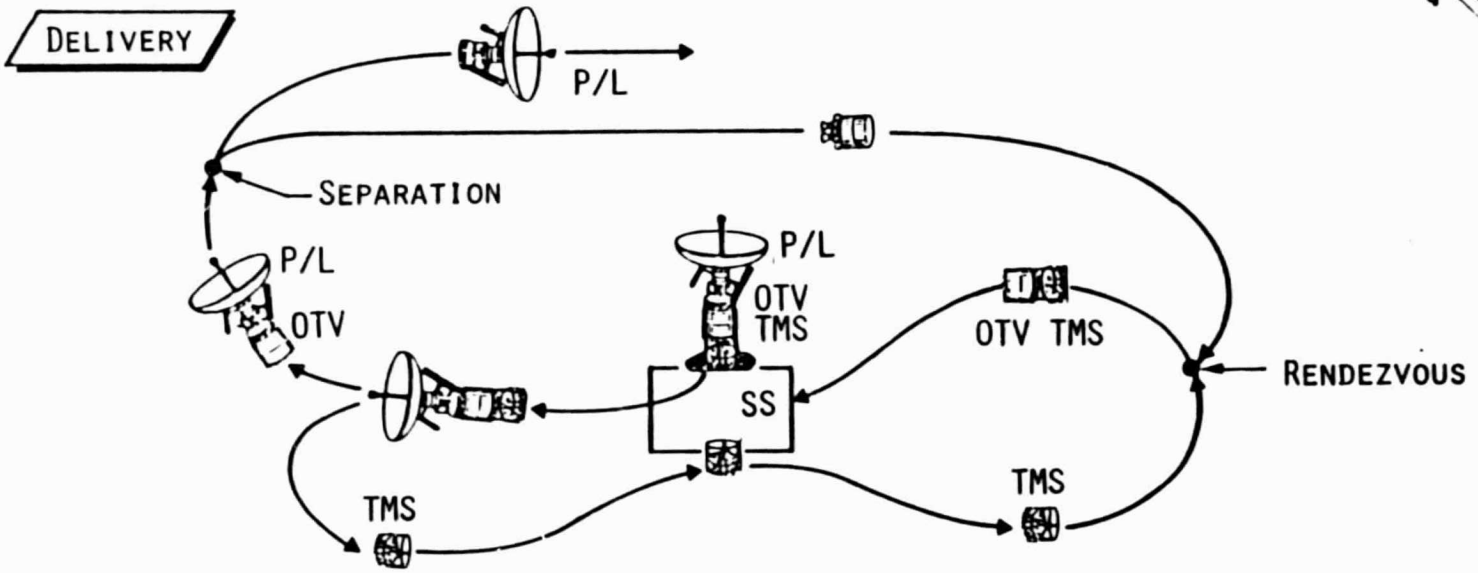
Functional Analysis Example—Orbit Transfer, Payload Delivery

Detailed functional and operational analysis conducted for all 18 scenarios.

- TDM Requirements Include Universal Docking System, Berthing System, Transfer Mechanism
- New Technology Capabilities Required—Reusable TMS, OTV, Operational Techniques

Func. Anal. Example–Orbit Transfer, P/L Delivery





TMS/OTV/ P/L MATING → INITIAL DEPLOYMENT FROM SS → P/L DELIVERY BY OTV → FINAL TMS SS RMS RETRIEVAL → TMS/OTV DEMATING

REQUIREMENTS

- UNIVERSAL DOCKING SYSTEM
- LOGISTICS SUPPORT
- BERTHING SYSTEM
- CONTROL STATION
- TRANSFER MECHANISM (SS RMS)
- MATING FACILITY

NEW TECHNOLOGIES

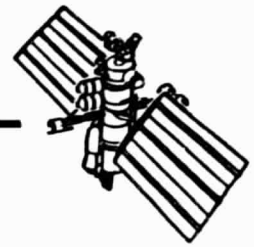
- REUSABLE VEHICLE REFURBISHMENT
  - POWER SYSTEM REPLACEMENT/ REFUELING
  - UNSCHEDULED MAINTENANCE
- OPERATIONAL TECHNIQUES
  - CONTROL TRANSFER OF OTV FROM SS TO GROUND CONTROL

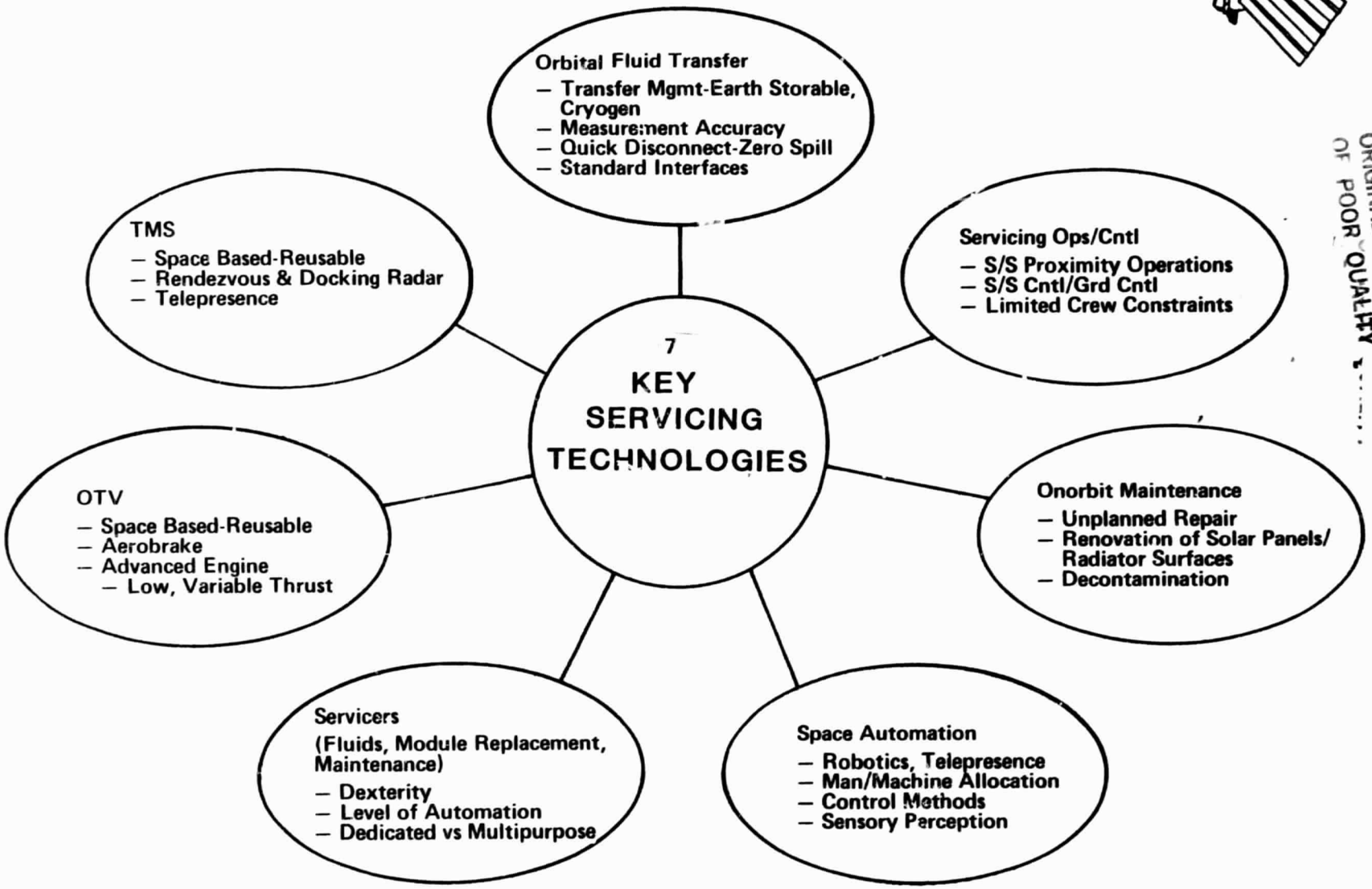
Key Technology Issues Identified

Seven key technology development areas identified.

- Fluid Transfer Issues Include Transfer, and Measurement of Storables and Cryogens
- Space-Based, Reuseable TMS Required for Servicing at Space Station
- Near-Term Technology Development for Space-Based OTV with Aerobrake Required
- Servicers for Remote Operations Identified
- Space Automation Technology Development Required for All Servicing Aspects
- Onorbit Maintenance Requires Substantial Technology Development
- Operations and Control Complicated by Complex Tasks and Minimum Crew

Key Technology Issues Identified





Evolutionary Technology Plan (ETP)—Fluid Transfer

Evolutionary technology plan was developed and provides technology development roadmap.

- Technology Status and TDM Requirements Compared for All Issues
- Fluid Transfer Example Shows Ongoing and Planned Technology for Each Storable and Cryogen
- NASA Preparing Ground and Shuttle Experiments Using Water/Hydrazine
- NASA Planning Cryogenic Fluid Management Facility (CFMF) for Cryogenic Transfer on Ground and Shuttle
- Additional Fluid Transfer Tests Recommended—MMS/Mark I and TMS/Mark II
- "Battleship Tank" Precursor Tests Required on Shuttle for TMS and OTV Before Space Station Tests
- Recommended Development of Automated Equipment and Procedures at Space Station—Ground, Shuttle, Space Station Tests
- Propellant Resupply—Related Issue—Studies Underway
- Earth Storable and Cryogen Tests Required at Space Station

Evolutionary Technology Plan–Fluid Transfer

TECHNOLOGY	GROUND	STS	SPACE STATION
ORBITAL FLUID TRANSFER (EARTH STORABLE)	MMC IR&D - ORBITER SUPPLY SYSTEM DESIGN (O) MMC IR&D - PROPELLANT TRANSFER (O) PROPELLANT XFER PROCEDURE DEVELOPMENT (R)	MMC - IR&D STORABLE FLUID MGMT DEMO (P) NASA - HYDRAZINE TRANSFER EXPERIMENT (P) MULTI-MISSION MODULAR SPACECRAFT (MMS) - MARK I PM TRANSFER (R) TMS/MARK II (R) TMS "BATTLESHIP TANK" FLUID XFER TESTS (R) FLUID TRANSFER CONTROL ALGORITHM DEVELOPMENT (R)	TMS/LOGISTICS MODULE FLUID TRANSFER DEMO (R) LOGISTICS MODULE/SS FLUID TRANSFER DEMO (R) TRANSFER CONTROL SYSTEM TEST & DEMO (R)
(CRYOGEN)	MMC IR&D - CRYOGEN TRANSFER & FILL (O) LaRC/MMC - DESIGN OF CRYOGENIC FLUID MGMT FACILITY (CFMF) (O) JSC/MSFC - PROPELLANT DELIVERY TO ORBIT (P) - ET SCAVENGING - AFT CARGO CARRIER - OMS RECOVERY/CAPTURE	CFMF FLIGHTS (P) OTV "BATTLESHIP TANK" FLUID XFER TESTS (R)	SS CRYOGEN STORAGE TANK FILL DEMO (R) OTV/CRYOGEN STORAGE TANK TRANSFER DEMO (R) CRYOGEN TRANSFER CONTROL SYSTEM TEST AND DEMO (R)

C - COMPLETE O - ONGOING P - PLANNED R - RECOMMENDED

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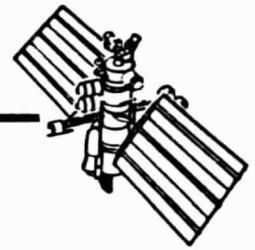

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Technology Development Missions

Operations Analysis

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Technology Development Mission (TDM)

Mission-level TDMs demonstrate satellite servicing capabilities.

- Mission-Level TDMs Define:
  - System/Subsystem Validation Requirements (Precursor TDMs)
  - Space Station Facility Requirements
  - Servicing Equipment
  - Operational Requirements
- Operational Satellites and Missions Chosen for TDMs

Technology Development Mission (TDM)

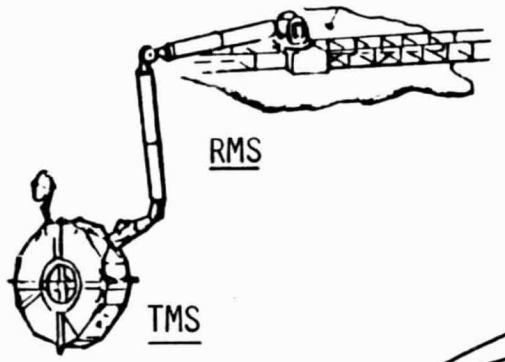
PURPOSE: DEMONSTRATE THE SATELLITE SERVICING OPERATIONAL CAPABILITY ON THE EARLY SPACE STATION

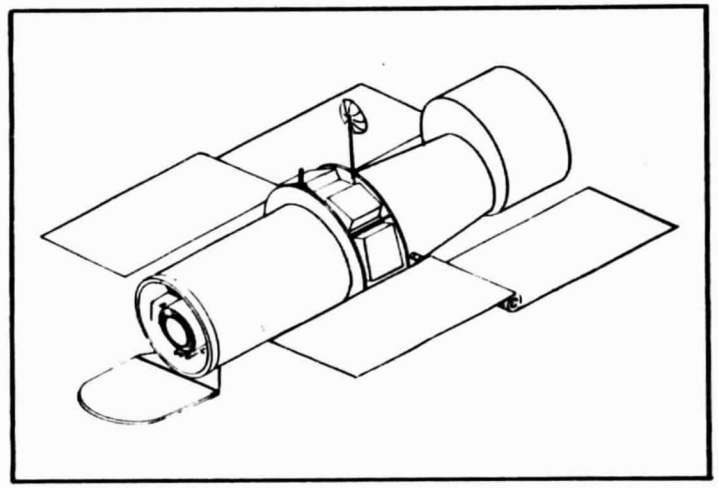
PRECURSOR TDM'S

SYSTEM/SUBSYSTEM VALIDATION REQUIRED TO SATISFY A MISSION LEVEL OBJECTIVE

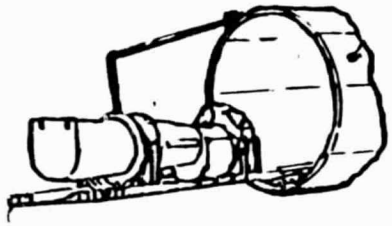
MISSION LEVEL TDM

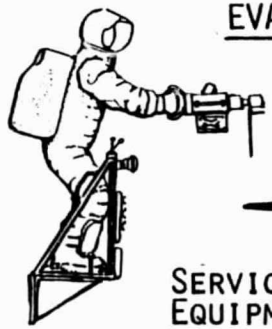
DEMONSTRATES A SPECIFIC SATELLITE SERVICING CAPABILITY OR SET OF CAPABILITIES. CONDUCTED EITHER AT OR REMOTE FROM THE SPACE STATION.





SERVICING BERTH (HANGAR)





EVA

SERVICING EQUIPMENT

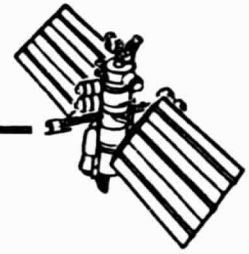
ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)

Satellite Servicing TDMs

Eight TDMs encompass all satellite servicing tasks.

— Objectives Defined for Eight TDMs

Satellite Servicing TDMs



TDM	OBJECTIVE
1	SPACE STATION ASSEMBLY, MODIFICATION, RESUPPLY AND MAINTENANCE
2	LEO TRANSFER RESUPPLY AND RETRIEVAL (SOLID OBJECTS)
3	ORBIT TRANSFER (GEO DELIVERY)
4	LARGE SPACECRAFT ASSEMBLY
5	RESUPPLY (CRYOGENS)
6	MAINTENANCE/DECONTAMINATION (EVA)
7	MAINTENANCE/MODULE(S) REPLACEMENT AND FLUID RESUPPLY (GENERAL PURPOSE ROBOTIC SERVICER)
8	RESUPPLY (FLUIDS AT GEO)

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TDM Operation Validation Analysis

TDM selections validated.

- Task/Location Matrix Analysis Verifies Servicing Requirements Satisfied
- Each TDM Demonstrates a Servicing Capability
- Multiple Tasks Conducted on 50% of TDMs (1, 2, 6, 7)

TDM Operation Validation Analysis

Task		Location		
		Space Station	Remote From Space Station	
			LEC	HEC
Large Structure Assembly/ Modification	Space Station Assembly/Maint	TDM 1	NA	NA
	Spacecraft Assembly	TDM 4	NA	NA
Orbit Transfer	Delivery	NA	TDM 2 4,5,6,7	TDM 3 8
	Retrieval	NA	TDM 2 6,7	NA
Resupply	Fluids Earth Storable	TDM 1 2,3,4,5,6,7,8	TDM 8	
	Fluids Cryogen	TDM 1 3,4,5,7,8	TDM 5	
	Materials, Large Modules	TDM 1 2	TDM 2	
Maintenance	Module Replacement	TDM 6,7	TDM 2	
	General Maintenance	TDM 6,7	NA	
	Decontam-ination	TDM 6	NA	

LEC - Low Energy Change
HEC - High Energy Change

Satellite Servicing—TDM 1 (Example)

TDM 1 demonstrates Space Station assembly and modifications.

— **TDM Time Phased for Space Station Evolution and Maintenance Requirement**

Satellite Servicing–TDM 1 (Example)

TDM	OBJECTIVE	DESCRIPTION	DATE	PRECURSORS
1	SPACE STATION ASSEMBLY, MODIFICATION, RESUPPLY, & MAINTENANCE.	ASSEMBLE DEPLOYED ENERGY SECTION AND INITIAL CREW HABITABILITY MODULE. INCREMENTAL SS MODIFICATIONS, RESUPPLY & MAINTENANCE. LOCATION: SPACE STATION	1990-1992	TMS VALIDATION FROM STS.

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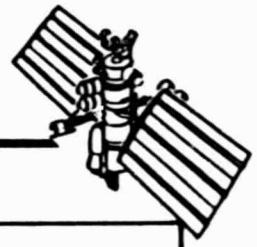
TDM 1: Space Station Assembly and Modification—Operations Analysis (Example)

TDM 1 demonstrates Space Station assembly service support.

— Operations Analysis Highlights Delivery, Assembly, and Checkout

— Top-Level TDM Requirements Are Displayed

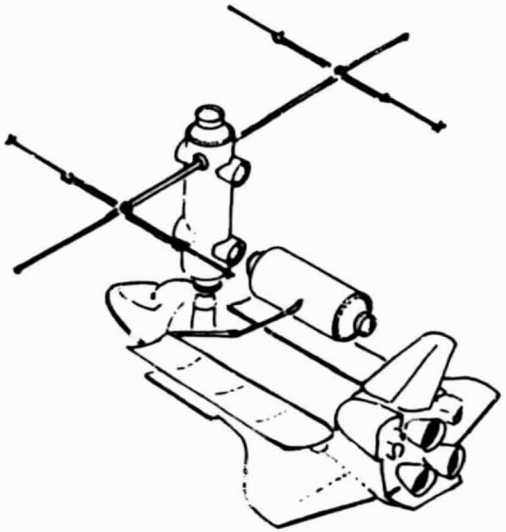
TDM 1: Space Station Assembly and Modification–Operations Analysis (Example)

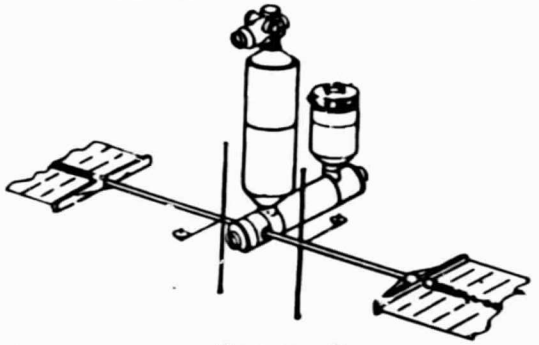


SHUTTLE DELIVERY, DEPLOYMENT, AND CHECKOUT OF SS ENERGY SECTION → SHUTTLE DELIVERY OF SS MODULES AND SUPPLIES → MATING OF SS MODULES AND SUPPLY TRANSFER → SYSTEM LEVEL CHECKOUTS

OPERATIONAL REQUIREMENTS

- STS
- TMS
- EMU/MMU
- GROUND/CREW COMMUNICATIONS AND CONTROL
- ASSEMBLY TOOLS, CCTV, LIGHTING
- ALIGNMENT EQUIPMENT
- SS RMS
- BERTHING SYSTEM
- ENVIRONMENTAL CONTROL (MAN, MATERIALS)
- CHECKOUT EQUIPMENT





TITLE:	SPACE STATION
INCLINATION:	28.5°
ALTITUDE:	460 KM/250 NM
S/C MISSION:	MANNED PLATFORM--MAINTENANCE OPERATIONS AND RESUPPLY BASE

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Satellite Servicing—TDM 4 (Example)

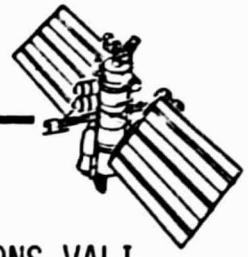
TDM 4 demonstrates onorbit assembly and delivery of large spacecraft.

— TDM 4 Time Phased for Use with Operational Satellite

— Multitasks Demonstrated in TDM— Assembly, and Delivery

— OTV Operations Validation Identified as Required Precursor

Satellite Servicing–TDM 4 (Example)



TDM	OBJECTIVE	DESCRIPTION	DATE	PRECURSORS
4	LARGE SPACECRAFT ASSEMBLY	ASSEMBLE ORBITING VERY LONG BASELINE INTERFEROMETER (OVLBI) AT SPACE STATION AND DELIVER TO LEO LOCATION: ASSEMBLE & C/O AT SS. DELIVERY - LEO 45°.	1993	OTV OPERATIONS VALIDATION, TEMPORARY SPACECRAFT ELEMENT STORAGE

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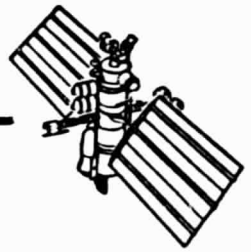
TDM4: Large Spacecraft Assembly—Operations Analysis (Example)

TDM4 demonstrates onorbit assembly and delivery of large spacecraft.

- TDM Conducted with Operational Satellite
- Multitask Mission Demonstrates Assembly and Delivery
- OTV Operations Validation Is Required Precursor

TDM 4: Large Spacecraft Assembly–Operations Analysis (Example)



SHUTTLE DOCKING & CARGO TRANSFER TO SS

OVLBI ASSEMBLY AND CHECKOUT

OVLBI/OTV/(TMS) MATING AND CHECKOUT

OVLBI/OTV/(TMS) DEPLOYMENT TO ORBIT TRANSFER POINT

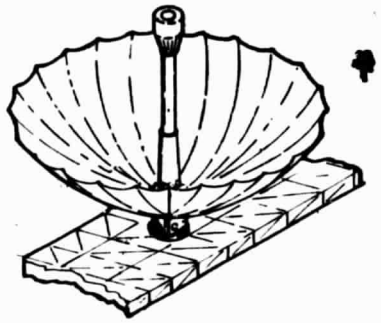
ORBIT TRANSFER *

OVLBI/OTV/(TMS) * DEMATING AND S/C ACTIVATION

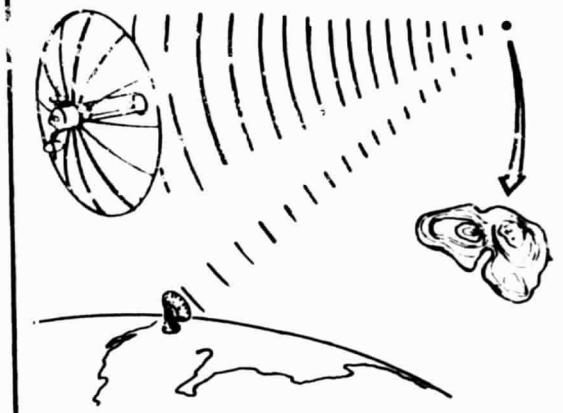
OTV/(TMS) RETURN *

OPERATIONAL REQUIREMENTS

- STS
- P/L BERTHING STATION, TOOLS, LOGISTICS
- EMU/MMU
- SPACE CRANE/RMS
- CRANE/RMS CONTROL CONSOLE
- CHECKOUT INSTRUMENTATION
- TMS
- OTV WITH AEROBRAKE
- TMS } CONSOLE TRADE
  OTV } (SINGLE/MULTI)



*GROUND CONTROL



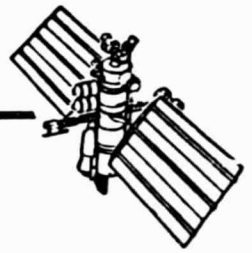
TITLE:	ORBITING VERY LONG BASELINE INTERFEROMETER (OVLBI)
INCLINATION:	45°
ALTITUDE:	800 KM/432 NM
S/C MISSION:	MAPS COMPACT CELESTIAL RADIO SOURCES

Satellite Servicing—TDM 7 (Example)

TDM 7 demonstrates module replacement, general repair, and fluid resupply capability.

- TDM 7 Time Phased to Correspond with Needs of Operational Satellite
- Retrieval and Servicing at Space Station Demonstrated
- Planned and Unplanned Maintenance Conducted
- General-Purpose Servicer Validated

Satellite Servicing–TDM 7 (Example)



TDM	OBJECTIVE	DESCRIPTION	DATE	PRECURSORS
7	MAINTENANCE/ MODULE(S) REPLACE-MENT AND FLUID RESUPPLY (GENERAL PURPOSE ROBOTIC SERVICER)	REPLACE DEFECTIVE/ OBSOLETE MODULE(S) AND RESUPPLY FLUID FOR ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF) AFTER RETRIEVAL FROM LEO FOR SERVICING AT SPACE STATION HANGAR USING GENERAL PURPOSE SERVICER. LOCATION: RETRIEVE LEO 28.5^{O}. SERVICE AT SPACE STATION.	1995	TMS OPERATIONAL VALI-DATION, GENERAL PURPOSE SERVICER VALIDATION

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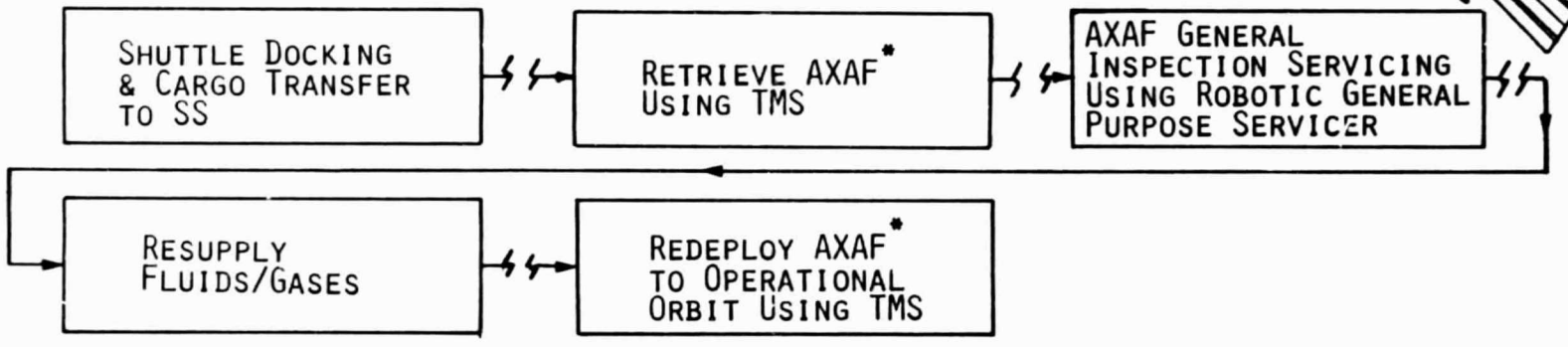
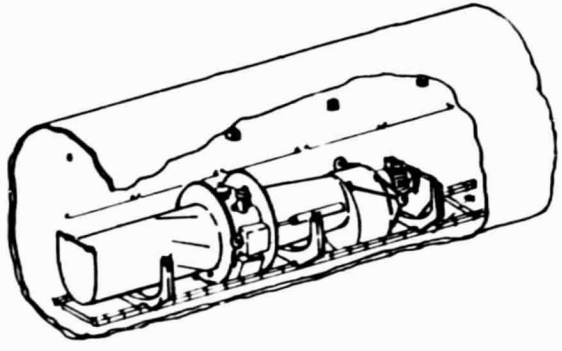
TDM 7: Maintenance and Module Replacement—Operations Analysis (Example)

AXAF repair, replace, and resupply mission demonstrates credible servicing capability at Space Station.

- AXAF Retrieval and Delivery by TMS Demonstrated
- Robotic General-Purpose Servicer Validated
- Repair, Replacement, and Resupply of Operational Spacecraft Demonstrated

TDM 7: Maintenance and Module Replacement–Operations Analysis (Example)

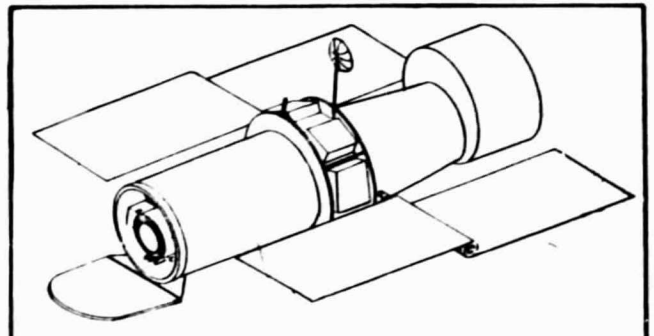




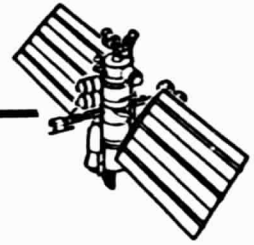
OPERATIONAL REQUIREMENTS:

- STS
- SPACE CRANE/RMS
- CRANE/RMS CONTROL CONSOLE
- EMU/MMU
- P/L BERTHING STATION (HANGAR), TOOLS, LOGISTICS
- GROUND/SS CREW COMM & CONTROL
- ROBOTIC GENERAL PURPOSE SERVICER
- AXAF CHECKOUT INSTRUMENTATION
- FLUIDS SERVICING EQUIPMENT
- TMS, OTV, SERVICER } CONSOLE TRADE (SINGLE/MULTI)

*GROUND CONTROL



TITLE:	ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)
INCLINATION:	28.5°
ALTITUDE:	400 KM/216 NM
S/C MISSION:	ASTROPHYSICS FACILITY FOR DETERMINING X-RAY SOURCES & PHYSICAL PROPERTIES



Accommodation Needs

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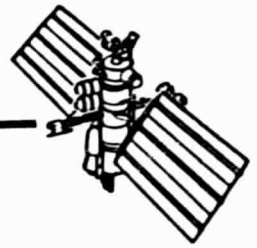
TDM 7: Servicing Requirements

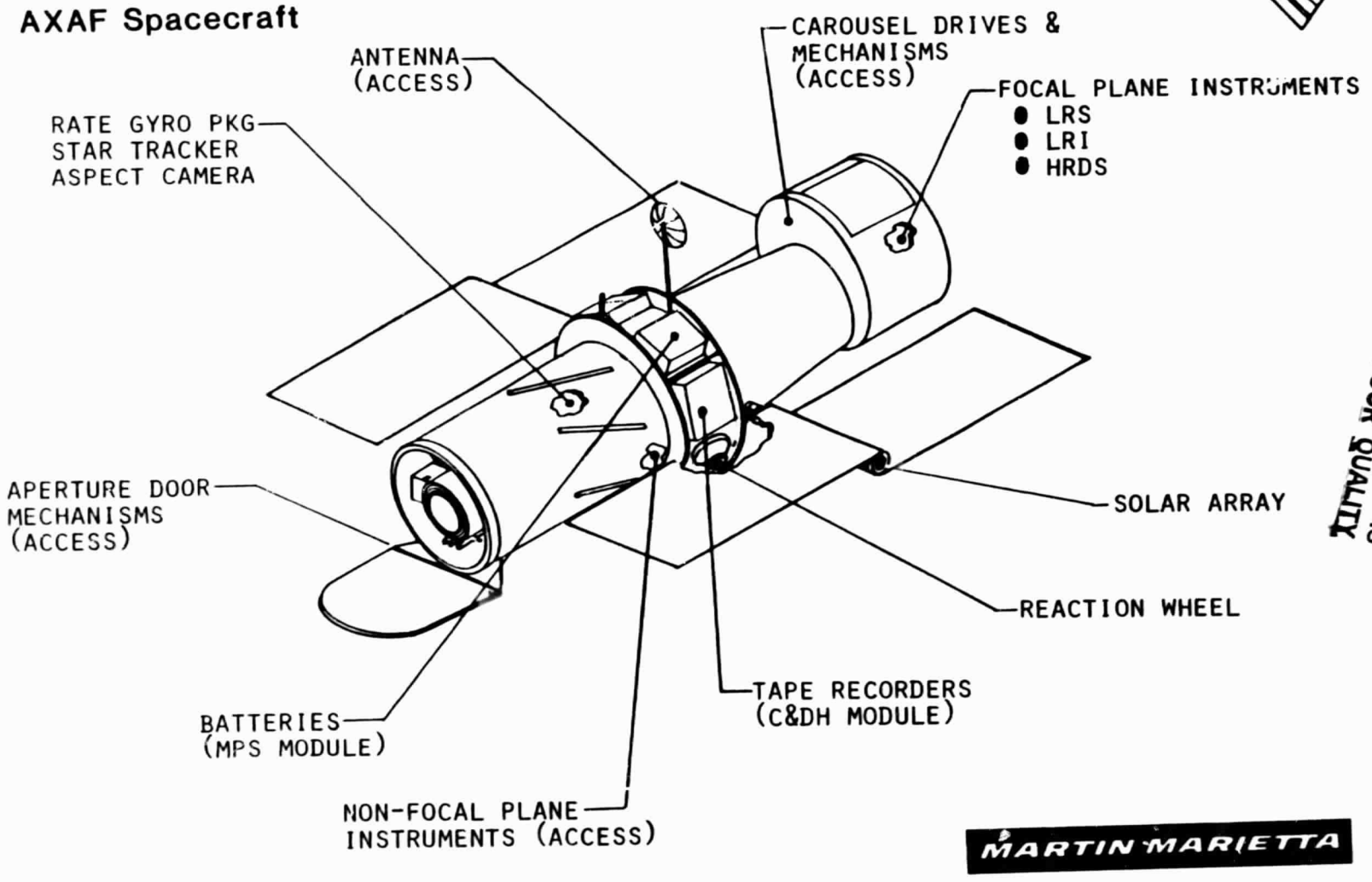
The AXAF spacecraft is an excellent servicing TDM candidate.

- AXAF Design Supports Onorbit Servicing
- Complex Servicing Requirements Identified
- Standard and Nonstandard Interfaces Exist
- Access Provided to Several Spacecraft Locations

TDM 7: Servicing Requirements



AXAF Spacecraft



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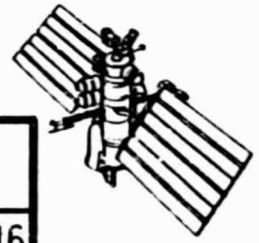
TDM 7: Interface Definition

Accommodation needs identified by interface analysis.

- Analyzed 16 Activities in Servicing Scenarios
- Identified More than 20 System and Subsystem Functional Interfaces
- Interfaces Included Physical, Operational, Crew, and rf
- Many Interfaces Capable of Standardization

TDM 7: Interface Definition



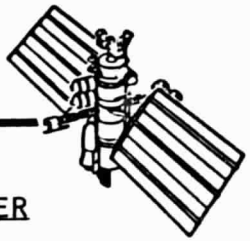
Interfaces	Servicing Activity Steps															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Structural/Mechanical																
Restraint/Stowage	X	X		X	X		X	X	X	X	X	X	X			X
Handle/Transfer	X	X		X	X		X	X	X	X	X	X	X	X		X
Remove/Replace	X							X								
Miscellaneous	X							X	X	X		X				
Electrical																
Supply Power/Grounding	X					X			X	X	X					X
Covers/Protection	X					X					X	X				
Propellants/Pressurant																
Storage	X								X	X						
Resupply/Replenish	X								X	X						
Thermal Control																
Control/Monitor	X					X				X	X					
Aux TCS						X		X								
Data Management																
Storage						X	X	X	X	X	X					
Processing/Control	X	X				X		X	X	X	X					
Video		X		X	X	X	X	X	X	X	X		X	X		X

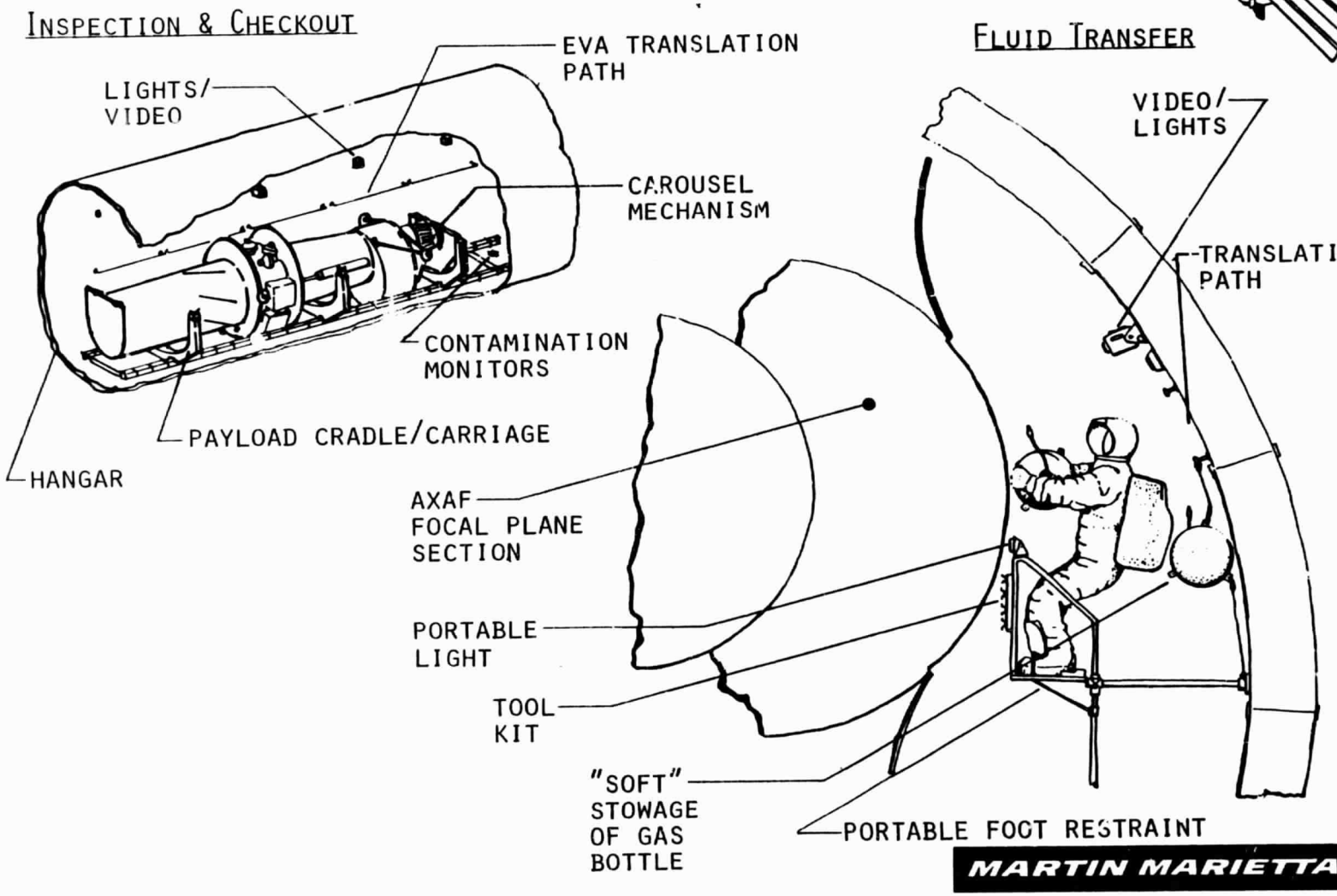
Servicing Activities Evaluation

Servicing scenario analysis provided TDM support equipment definition.

- Multiposition Translation Carriage Improves EVA Efficiency
- First Use of General-Purpose Manipulator Servicer
- Multiposition Crade/Carriage Reproduces Cargo Bay
- Cradle Carriage and Carousel Mechanism Adaptable to Multiple Payloads

Servicing Activities Evaluation





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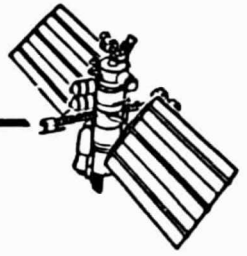
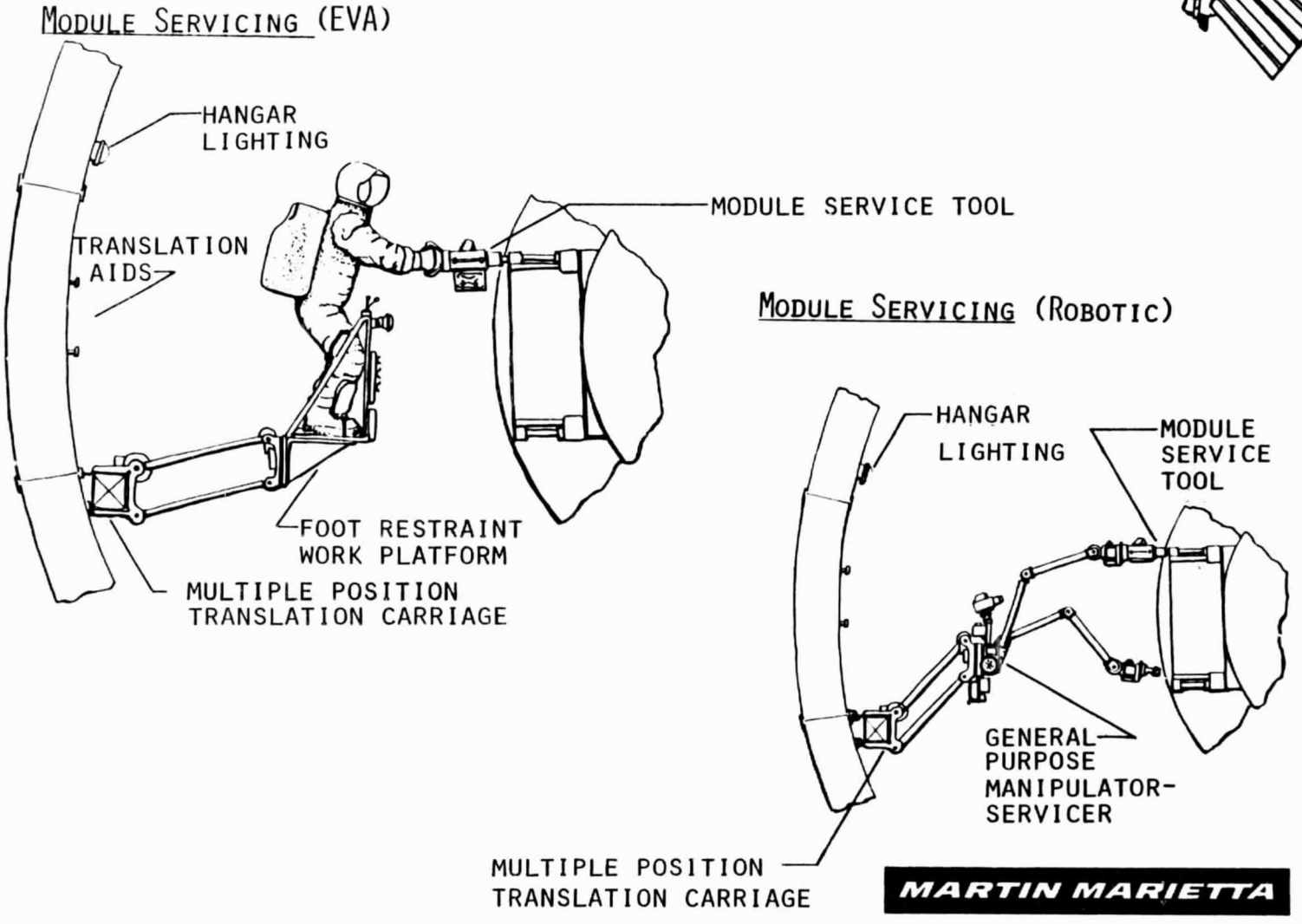
Servicing Activities Evaluation



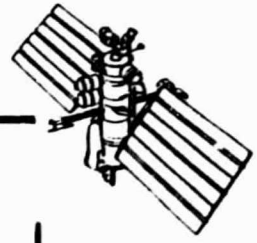


Support Equipment

Accommodation needs identified for TDM 7 include unique and multipayload equipment.

- Major, Complex Accommodation Needs Are Part of Early Space Station Capability
- More than 50% of Support Equipment Is Not Unique to TDM 7
- Most Support Equipment Technology Is Adequate

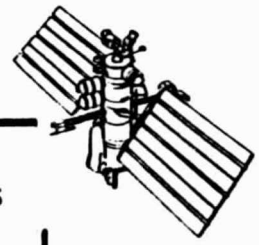
Support Equipment



Support Equipment	Development Status A	B	C
Structural/Mechanical:			
Storage for TMS, ORU, Tools, EMU	X		
Space Crane/RMS		X	
Payload Cradle/Carriage	X		
Carousel/Servicing Mechanism	X		
Multiple Position Translation Carriage	X		
EVA Translation Aids	X		
EVA Portable Foot Restraint	X		
Servicing Tools		X	
Tethers, Lanyards, etc	X		
Module Service Tools (MMS)	X		
General Purpose Robotics Servicer		X	
Electrical:			
Power Supply and Control	X		
Umbilical Connection		X	
Protective Covers	X		

A - Current Technology
B - Extension of Current State-of-the-Art (SoA)
C - New Technology Development

Support Equipment (Cont.)



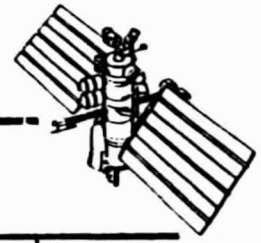
Support Equipment	Development Status A	B	C
Data Management:			
Data Processing and Control	X		
Storage		X	
Software	X		
Displays/Keyboard	X		
Communications:			
RF Sets (TMS and EVA)	X		
Rendezvous Radar (TMS)		X	
Rendezvous Radar (SS)			X
Serv Antenna Hat/Umbilical	X		
Propellant Rdsupply:			
Storage for Gases and Fluids		X	
Pressurant Transfer		X	
Fluid Transfer			X
Vent/Containment Hardware		X	

Support Equipment Commonality

Evaluation of TDMs reveals a tendency toward commonality of support equipment needs.

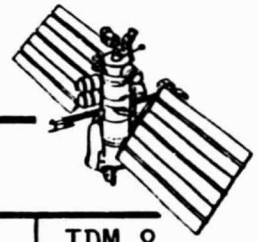
- **Functional Interface Needs Are Similar**
- **Interface Adapters Can Be Used Effectively**
- **Structural and Electrical Commonality Is More Apparent than Fluid Resupply**

Support Equipment Commonality



TDM 7 Support Equipment	TDM 1 SS Assy	TDM 2 Resupply	TDM 3 Geo Xfer	TDM 4 LSS Assy	TDM 5 Resupply Cryo	TDM 6 Refurb	TDM 8 Resupply Geo
• Storage Provisions		X	X	X	X	X	X
• SS RMS		X	X	X	X	X	X
• Payload Cradle		X	X*	X		X	
• Carousel Mechanism						X*	
• Robotics Servicer		X*remote			X*remote		X*remote
• Universal Service Tool						X	
• SS Tool Kit	X			X		X	
• EVA Translation	X	X		X		X*	
• EVA Restraint	X	X		X*		X	
• Tethers/Landyards	X	X		X		X	
• Power Supply/ Controls			X*	X*		X*	
• Umbilical Connection			X*	X*		X*	
• Protective Covers Elect/Other						X*	
• RF Sets		X	X	X	X	X	X
• Radar		X	X	X	X	X	X

Support Equipment Commonality (Cont.)



TDM 7 Support Equipment	TDM 1 SS Assy	TDM 2 Resupply	TDM 3 Geo Xfer	TDM 4 LSS Assy	TDM 5 Resupply Cryo	TDM 6 Refurb	TDM 8 Resupply Geo
• Ant/Cable Coupler				X*		X*	
• Data Display				X	X	X	X
• Data Storage				X		X	
• Data Proc/Control		X		X	X	X	X
• Video		X	X	X	X	X	X
• Software			X*	X*	X	X*	X
• Contam Monitor			X			X	
• Lighting		X	X	X*	X	X*	X
• Safety Eq/Proc		X		X	X	X	X
• Gas Storage					X*		X*
• Fluid Storage					X*		X*
• Pressurant Xfer					X*		X*
• Fluid Transfer					X*		X*
• Vent Equipment					X*		X*
• EMU Resupplies		X		X		X	
• Service Procedures		X*	X*	X*	X*	X*	

*Potential Unique Equipment/Software Required or Adapters Needed

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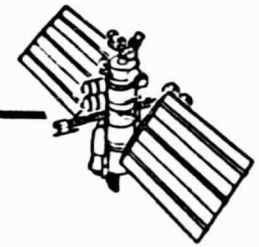

Programmatic Analyses

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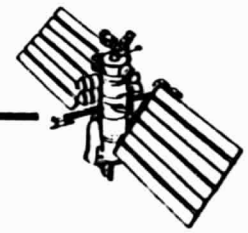
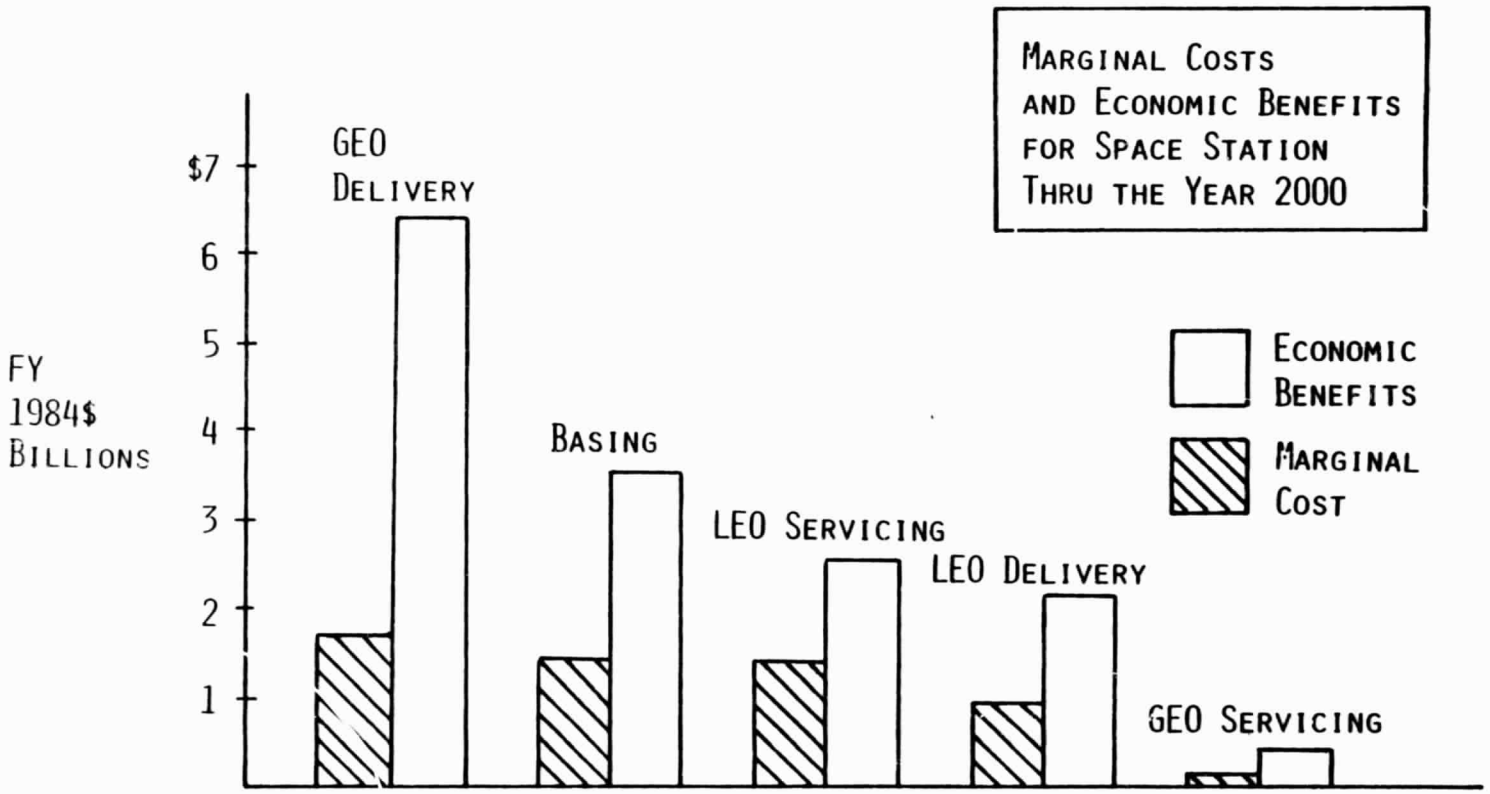
Marginal Cost and Economic Benefits by Capability Increment

Servicing tasks with the largest economic payoff were used to establish the priority for each TDM.

- Economic Benefits Compare Servicing Based at Space Station versus Shuttle
- Marginal Cost Is the Additional Cost of Providing That Capability
- Economic Benefits Are Primarily Transportation Cost Avoidance

Marginal Costs and Economic Benefits by Capability Increment





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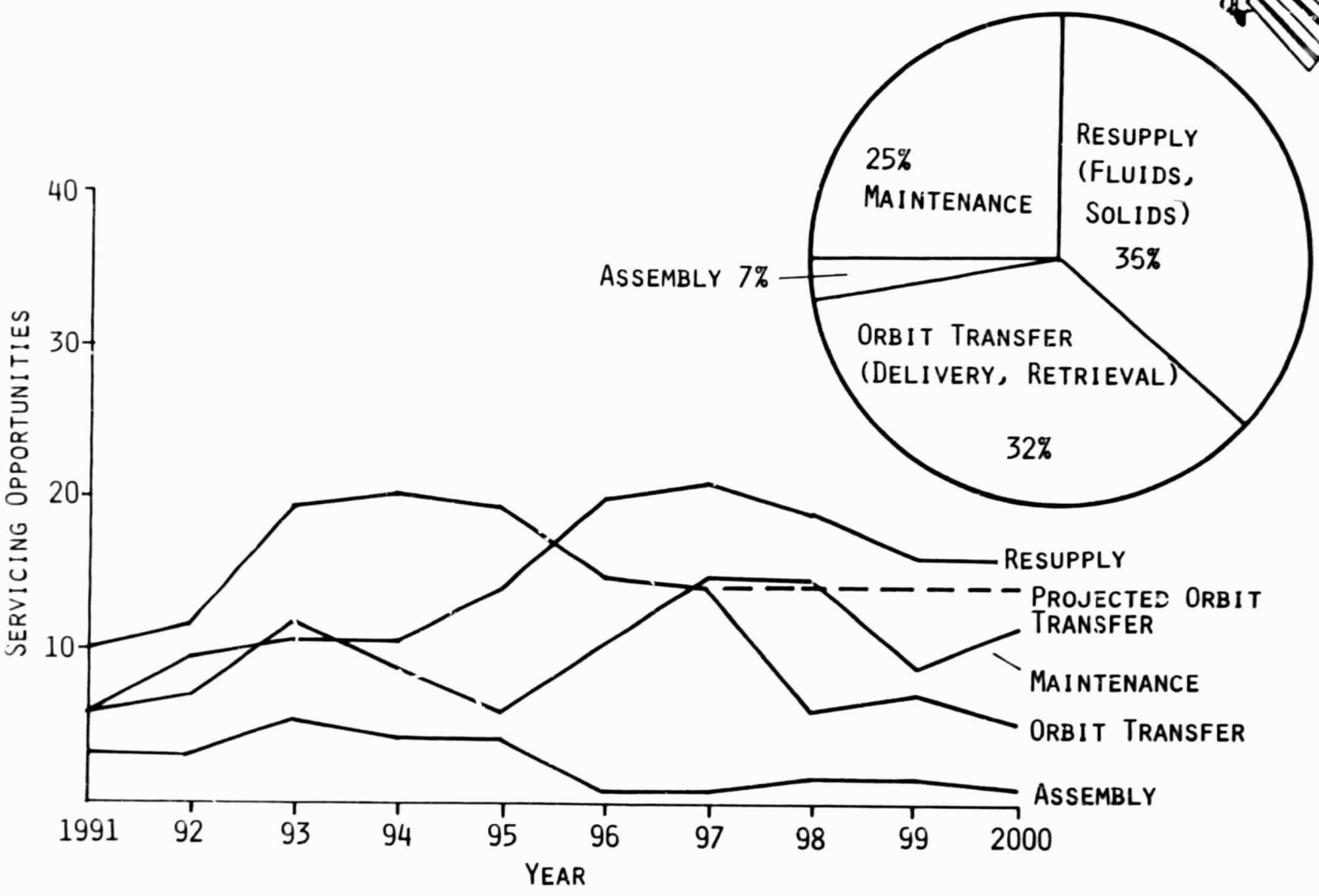
Time Phased Servicing Tasks

Mission model analysis revealed early and increasing opportunities to perform cost-effective servicing.

- Orbit Transfer Is a Major Early Servicing Opportunity
- Demand for Resupply and Maintenance Grows in Mid-1990s

Timed Phased Servicing Tasks

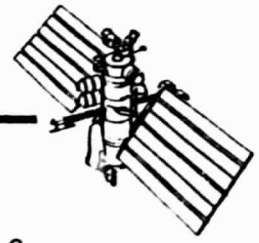


Critical Items

Analysis of critical service elements identified risk and high payoff areas.

- **All Result in High Economic Payoff**
- **Most Have Critical Technical or Schedule Risks**

Critical Items



Critical Items	High Payoff	Technical Risk	Development Span	Critical Path
OTV - Space Based, Aerobraked	X	X	X	X
Rendezvous and Docking System	X	X	X	
TMS - Space Based	X	X		
Spacecraft Standardization	X		X	
Orbital Fluid Transfer	X	X		

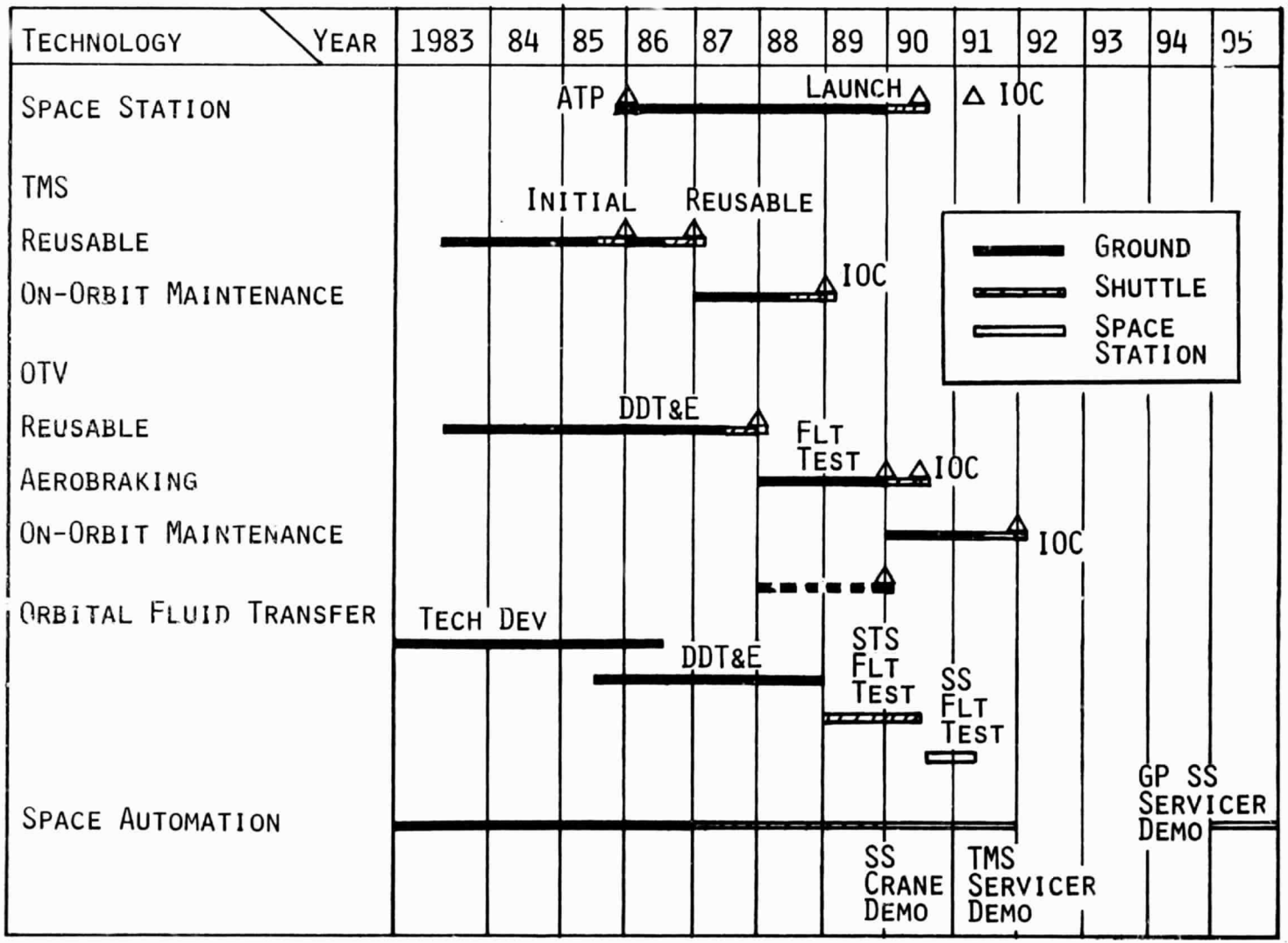
Critical Precursor Technology Schedules

Critical technology development issues are time-phased.

— **Technologies Require Precursor Ground and Shuttle Development Efforts**

— **Development of Space-Based TMS and OTV Vehicles Critical to Early Servicing from Space Station**

Critical Precursor Technology Schedules

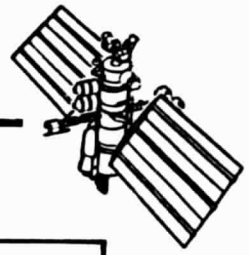


Technology Development Missions Schedule

TDMs with largest economic payoff are scheduled early.

- TDMs 1 and 2 Are a Set of Missions Accomplished over Span Shown
- GEO Orbit Transfer TDM Schedule Is Constrained by OTV Development Timeline

Technology Development Missions Schedule



TDM	Year	1990	1991	1992	1993	1994	1995	1996	1997
1	Space Station Assembly								
2	LEO Transfer, Resupply & Retrieval								
3	Orbit Transfer (GEO)								
4	Large S/C Assembly								
5	Resupply (Cryogen)								
6	Maintenance/Module Replacement (EVA)								
7	Maint./Module Replace (Gen. Purpose Robotics Ses.)								
8	Resupply Fluids at GEO								

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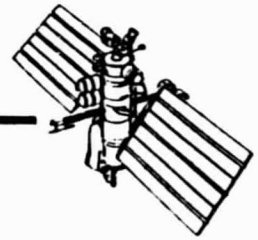
TDM 7: Associated Costs

Selecting existing and planned missions produces cost-effective TDMs.

— Sharing Costs with the User and Space Station Lowers TDM-Unique Costs

TDM 7: Associated Costs



TDM Costs

AXAF Mission Unique Costs $22M

- Ops Planning & Support
- AXAF Cradle
- Replacement Module Storage
- Checkout Support Equipment
- Umbilicals

Space Station Common Costs $38M

- General Purpose Robotic Servicer
- Payload Carriage
- Carousel Mechanism
- Module Service Tool

TDM 7 Unique Costs $7.4M

- Research & Technology
- Operations Planning & Support
- Experiment Hardware
- Support Equipment

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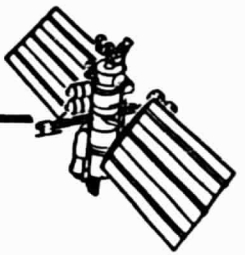
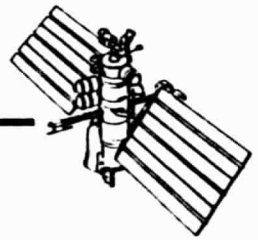
Conclusions



- SATELLITE SERVICING TASKS/LOCATIONS/SCENARIOS ARE SATISFIED WITH EIGHT TDMs.
- THE SPACE STATION MISSION MODEL PROVIDES MANY OPPORTUNITIES TO CARRY OUT THE TDMs AND DEMONSTRATE SATELLITE SERVICING OPERATIONAL CAPABILITY BY THE LATE 1990s.
- MANY TDM SUPPORT ACCOMMODATIONS ARE SATISFIED BY REQUIRED SPACE STATION ARCHITECTURAL ATTRIBUTES.
- NEW SUPPORT EQUIPMENT COMMONALITY EXISTS ACROSS OUR RECOMMENDED TDMs (MINOR MODIFICATIONS/ADAPTERS LIKELY).
- STANDARD PAYLOAD INTERFACES ARE REQUIRED TO PERFORM AUTOMATED SERVICING OF PAYLOADS/SATELLITES.
- MAINTAINABILITY MUST BE DESIGNED INTO FUTURE HARDWARE THAT REQUIRES HANDS-ON OR EVA SERVICING.

Conclusions (Cont)



- IDENTIFIED SERVICING ISSUES SHOULD BE RESOLVED TO PROVIDE STUDY DIRECTION AND TO SUPPORT SATELLITE SERVICING PLANNING ACTIVITIES.
- USING REAL MISSIONS TO DEMONSTRATE SATELLITE SERVICING OPERATIONAL CAPABILITY REDUCES UNIQUE COST OF TDMs.
- EARLY SPACE STATION PROVIDES FLEXIBLE "TEST BED" FOR SERVICING PROCEDURES BEFORE IN SITU OPERATIONS.